

Durability of Jute Fibre-Reinforced Concrete: A Critical Review of Degradation Mechanisms, Mitigation Strategies and the Quantitative Evidence Base

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Abstract: Jute is among the most abundant and lowest-cost renewable reinforcing fibres available in South and Southeast Asia, and a substantial body of work confirms that it improves the tensile, flexural and impact performance of cement-based composites. The property that governs service use — durability — is nonetheless far less consolidated. Both existing reviews of jute in cementitious composites are, by their own inclusion criteria or conclusions, accounts of mechanical strength: one screened 937 records and analysed 143 strength studies, while the other concluded that little research exists on jute-reinforced concrete durability. This review addresses that imbalance and, where jute-specific data are absent, maps onto jute the degradation mechanisms established for analogous lignocellulosic fibres. Five findings emerge. First, degradation is governed by the alkaline pore environment through calcium hydroxide mineralisation of the fibre cell wall and alkaline hydrolysis of lignin and hemicellulose, proceeding in stages in which interfacial damage precedes loss of fibre strength. Second, jute is the most chemically vulnerable of the common plant fibres yet ranks second only to basalt in interfacial bond and composite strength, because it begins from much higher initial strength; vulnerability and adequacy are distinct questions. Third, the durability-optimal dosage appears lower than the strength-optimal 1–2%, since acid-induced strength loss and water absorption both rise with fibre content. Fourth, combined mild-alkali and dilute-polymer modification preserves 17–20% more fibre tensile strength than raw jute after 360 days in cement paste and pore solutions, acting by halving water absorption. Fifth, a first-order analysis performed here shows that replacing half the Portland cement with metakaolin reduces the toughness decay constant from 0.181 to 0.020 per wet–dry cycle, a ninefold reduction corroborating an independently reported 13.7-fold extension of cellulose service life. Contrary to expectation, freeze–thaw is the one environment in which plant fibres, including jute, improve performance. Remaining gaps are identified and prioritised.

Keywords: Jute Fibre; Fibre-Reinforced Concrete; Durability; Alkaline Degradation; Fibre Mineralisation; Degradation Kinetics; Fibre Surface Treatment; Supplementary Cementitious Materials.

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I. INTRODUCTION

Concrete is the most widely used construction material in the world, but its low tensile strength, brittleness and susceptibility to cracking continue to constrain its performance. Discrete fibre reinforcement is a well-established response to these limitations: fibres bridge micro-cracks, redistribute internal stresses, and convert a brittle matrix into one capable of post-cracking energy absorption. Historically this role has been filled by steel and synthetic polymer fibres, but the environmental cost and expense of these materials have driven sustained interest in plant-based

alternatives that are renewable, biodegradable, locally available and inexpensive [15].

Among plant fibres, jute (*Corchorus olitorius* and *Corchorus capsularis*) is of particular importance. It is a bast fibre extracted from the outer bark of the plant stem [15], produced at scale in Bangladesh, India and neighbouring countries, and available at a fraction of the cost of manufactured fibres. Its availability is not marginal: of the 32.4 million tonnes of natural fibre produced globally in 2024, jute accounted for 3.2 million tonnes, second only to cotton and roughly three times the volume of coir [9]. Its relatively

high cellulose content confers a tensile strength that compares favourably with other plant fibres, and the accumulated experimental record shows that incorporating jute into concrete and mortar improves tensile, flexural and impact performance and reduces crack propagation [2, 7, 18].

The difficulty is that this favourable short-term picture does not, by itself, justify structural use. A fibre-reinforced composite is only as useful as its ability to retain mechanical and functional performance over its intended service life [4]. Plant fibres are porous, hydrophilic and chemically composed of cellulose, hemicellulose and lignin — constituents that are not stable in the highly alkaline pore solution of a Portland cement matrix, where pH typically lies between 11 and 13 [8]. The consequence is a well-documented tendency for lignocellulosic fibre-cement composites to embrittle with age, losing precisely the toughness and post-cracking ductility for which the fibres were introduced [13, 16].

Despite this, the durability of JFRC specifically has attracted far less attention than its mechanical performance, and the structure of the existing review literature demonstrates the imbalance directly. Two dedicated reviews of jute fibre in cementitious composites have been published. Song et al. [17] conducted a systematic survey that identified 937 records, screened them to 180 included papers and analysed 143, but their stated inclusion criteria admitted only studies reporting tensile, compressive or flexural strength and explicitly excluded other loadings; the review is therefore, by construction, an account of mechanical performance rather than durability. Ahmad et al. [2] surveyed fresh, hardened and durability characteristics and concluded in the abstract that "there is little research available on the durability of concrete reinforced with JTF", recommending detailed durability studies as a priority for future researchers.

The position is thus that the mechanical behaviour of jute in cement has been consolidated twice over from a corpus of well over a hundred experimental studies, while its durability has been consolidated not at all, and the one review to address the question concluded that the underlying evidence was scarce. Song et al. [17] additionally record that publication on jute in concrete was negligible before 2011 and peaked at 35 articles in 2020, so the imbalance is not a historical artefact of a small literature but a persistent feature of an actively growing one. The same conclusion has been reached independently and more recently by Alassaad et al. [3], whose review of bio-based fibre-reinforced cementitious composites identifies as major knowledge gaps the lack of standardised accelerated ageing protocols, limited long-term field performance data, and the absence of predictive degradation models. Recent experimental work on JFRC echoes the point, with Alene [4] explicitly recommending long-term durability studies under aggressive alkaline environments, moisture cycling and weathering to better understand fibre degradation mechanisms over time.

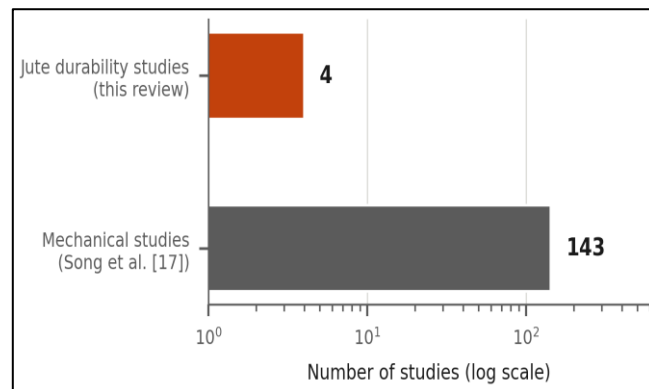


Fig 1 The asymmetry between the two literatures on jute in cementitious composites. Song et al. [17] screened 937 records and analysed 143 experimental studies of mechanical strength; the present review identified four studies subjecting jute or jute composites to a defined aggressive exposure. Logarithmic scale.

➤ *This Review Responds to that Gap. Its Objectives are:*

- To establish the chemical and physical characteristics of jute fibre that determine its durability in a cementitious matrix;
- To synthesise the available evidence on the degradation of JFRC, distinguishing clearly between findings obtained on jute itself and those transferred from analogous lignocellulosic fibres;
- To evaluate the two principal mitigation strategies — fibre surface treatment and matrix modification — in terms of their demonstrated effectiveness, including a quantitative characterisation of the rate at which composite toughness is lost under cyclic exposure; and
- To identify, precisely and with supporting evidence, the questions that remain open.

The scope is deliberately narrower than that of previous reviews. Where earlier work has surveyed the mechanical performance of jute in concrete broadly [2] or the behaviour of plant fibres in cement composites generally [15], the present review concentrates on durability and on the mechanisms that govern it. Mechanical performance is treated only insofar as it establishes the dosage regime within which durability must be assessed.

II. SCOPE AND METHOD

Because several conclusions of this review are statements about what the literature does *not* contain, the basis on which that literature was assembled is set out explicitly.

Records were located by searching the ScienceDirect, SpringerLink, MDPI, PubMed Central, Frontiers and Directory of Open Access Journals (DOAJ) platforms, together with Google Scholar, using combinations of the terms *jute*, *natural fibre*, *plant fibre*, *lignocellulosic*, *cement*, *concrete*, *durability*, *degradation*, *alkaline*, *accelerated ageing* and *fibre treatment*, and by citation tracking through the reference lists of the existing reviews of jute and of plant-fibre cement composites. The search covered publications

available to July 2026. Titles and abstracts were screened for relevance to the durability or degradation of jute, or of lignocellulosic fibres, in cementitious matrices. Full texts were then assessed against the criteria in Table 1, and studies

reporting no durability or degradation outcome were excluded unless required to establish the dosage regime (Section IV) or the degradation mechanism (Section V-A). The process is summarised in Figure 1.

Table 1 Inclusion and Exclusion Criteria Applied in Assembling the Evidence Base.

Inclusion	Exclusion
Experimental studies of jute fibre in cement paste, mortar or concrete	Studies of jute in polymer or epoxy matrices only
Studies of lignocellulosic fibres in cementitious matrices reporting a degradation or durability outcome	Studies reporting only fresh or 28-day mechanical properties, unless used to establish dosage
Reviews consolidating jute or plant-fibre cement composites	Non-English language publications
Studies characterising fibre degradation mechanism (spectroscopic, thermogravimetric, microstructural)	Numerical or analytical studies without experimental validation
Studies reporting a defined aggressive exposure with a measured response	Conference abstracts without full data

Twenty studies form the evidence base: five reporting jute-specific durability or degradation outcomes, eight on analogous plant fibres, four reviews, and three establishing

supporting mechanisms or properties. The full characteristics of each are given in Table 2.

Table 2 Characteristics of the Studies Forming the Evidence Base.

Ref.	Fibre	Dosage (basis)	Exposure	Duration	Principal response variable
[1]	Jute	5% by cement mass (0.8 vol%)	Freeze–thaw	10, 20, 30 cycles	Mass loss, strength, dynamic modulus
[4]	Jute	3% (constituent replacement)	None	28 d	Compressive strength, density
[6]	Jute textile	3 and 5 fabric layers	None	28 d	Tensile stress, crack spacing
[7]	Jute, sisal, sugarcane, coconut	0.5–3% by mass	None (water absorption)	28 d	Strength, impact, water absorption
[8]	Jute, sisal, sugarcane, coconut, basalt	2% by weight	NaOH and Ca(OH) ₂ immersion	1 wk; 48 h (1–6 M)	Weight loss, tenacity, IFSS, pull-out
[10]	Jute	Fibre level	Cement paste, saturated lime, 0.1 N NaOH	7–360 d	Tensile strength; FTIR, XRD, NMR, SEM–EDS
[11]	Jute	0.1, 0.2, 0.4% by volume	None	28 d	Compressive, split tensile, workability
[18]	Jute	0.5, 1.0, 1.5%	0.5 N H ₂ SO ₄ curing	28 d	Compressive, split tensile, slump
[20]	Jute + steel (hybrid)	0.5–1.5% + 1–3% steel	None	28 d	Compressive, tensile, flexural
[5]	Kraft pulp, cotton linters	4% by weight	Wet–dry cycling	4 cycles	Flexural, compressive, fracture energy
[9]	Spanish broom, sheep wool	0.5% by binder mass	Freeze–thaw	56 cycles	Flexural, fracture energy, abrasion
[12]	Eucalyptus pulp	—	Wet–dry cycling	200 cycles	MOR, specific energy
[13]	Sisal	5% by volume	Wet–dry; natural ageing	25 cycles; 28 d–5 yr	Flexural, toughness, crack count
[14]	Hemp, flax	1% by volume	Freeze–thaw in 3% NaCl	56 cycles	Compressive, flexural, scaling, energy
[16]	Sisal (aligned)	10% by volume	Hot-water immersion, 60 °C	6 months	MOR, toughness, sorptivity
[19]	Sisal	Fibre level	Cement pore solutions	—	Tensile, crystallinity, service life
[2], [3], [15], [17]	Reviews	—	—	—	—

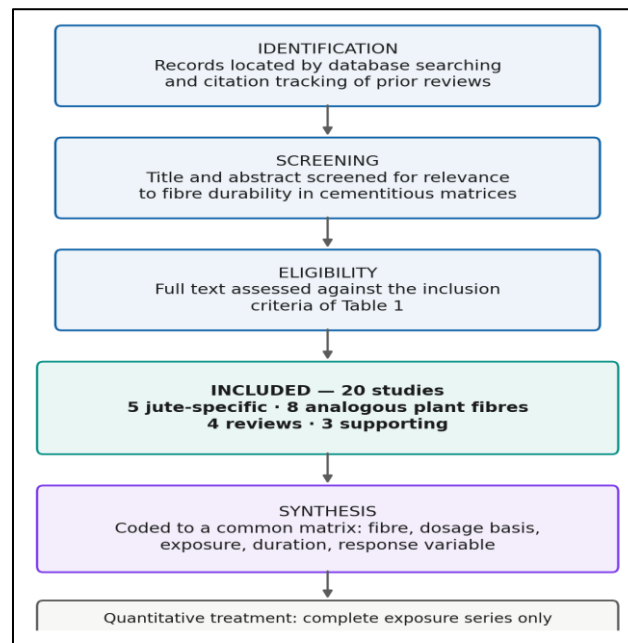


Fig 2 Assembly of the Evidence Base. Quantitative Treatment (Section V-I) was Confined to the Subset of Studies Reporting a Complete Exposure Series Rather than Endpoint Values Alone.

➤ Coverage of the Evidence Base

Coding the included studies by exposure type and fibre family (Figure 2) shows where evidence exists, at what level, and where it is absent. Two features of that map govern the structure of this review.

The first is that evidence for jute is concentrated in single-exposure studies and, where long-term data exist, is confined to the fibre rather than the composite. The second is

that the exposures for which composite-level evidence is richest — wet-dry cycling and hot-water immersion — are precisely those for which no jute data exist, while the exposure for which jute data do exist, freeze-thaw, is one of the least studied for the analogous fibres on which the mechanistic understanding rests. The transfer of mechanism from sisal and wood pulp to jute, discussed in Section VII-C, is therefore not a transfer across fibres alone but across exposure regimes as well.

Alkaline immersion	F	—	F	F
Long-term cement / pore solution	F	—	C	C
Acid attack	C	—	—	—
Wet-dry cycling	—	—	C	C
Freeze-thaw / salt scaling	C	C	—	C
Hot-water immersion	—	—	C	—
Carbonation	—	—	—	—
Chloride ingress	—	C	—	—
Sulphate attack	—	—	—	—
	Jute	Hemp, flax	Sisal	Other plant

— none **F** fibre level **C** composite

Fig 3 Evidence Coverage by Exposure Type and Fibre Family, Coded from the studies in Table 2. "Fibre" Denotes Evidence Obtained on the Fibre in Isolation; "Composite" Denotes Evidence Obtained on a Fibre-Reinforced Cementitious Composite. The Jute Column is Outlined.

III. JUTE FIBRE: COMPOSITION, PROPERTIES AND DURABILITY IMPLICATIONS

The durability behaviour of any plant fibre in cement follows from its chemistry and morphology, so these are set out first.

➤ Chemical Composition

Jute is a lignocellulosic fibre composed principally of cellulose, hemicellulose and lignin, with minor quantities of pectin, wax and other extractives. Ahmad et al. [2] give a cellulose content of 61–72%, lignin of 12–13% and crystallinity of 60–65%, and Jamshaid et al. [8] report values in the same ranges for the jute used in their experimental programme.

These figures should not, however, be treated as fixed material constants. Song et al. [17] compiled reported compositions from ten independent sources and found cellulose ranging from 45% to 74.4%, hemicellulose from 11.9% to 22.5% and lignin from 6.6% to as much as 40–45%, together with moisture contents between 12.5% and 14% where reported. Since lignin and hemicellulose are the constituents preferentially attacked in alkaline conditions (Section V-A), a lignin content varying by a factor of six across the literature implies that the susceptibility of jute to alkaline degradation is itself variable between cultivars, growing conditions and retting practices. This variability is rarely acknowledged in durability studies, which typically characterise a single fibre source, and it is one reason that results from different laboratories may not be directly comparable.

This composition matters because the three principal constituents behave very differently in alkali. Cellulose is comparatively stable and is the constituent responsible for the fibre's mechanical performance; it is largely insoluble in alkaline solution. Hemicellulose, by contrast, is a branched, highly reactive and non-crystalline polymer that dissolves readily, while lignin is soluble in alkaline solutions to a limited extent [8]. Because lignin and hemicellulose together form the

middle lamella that binds the individual fibre-cells into a coherent bundle, their preferential dissolution has structural consequences well beyond their mass fraction: it disaggregates the fibre.

Jute's high cellulose content is thus a double-edged characteristic. It underlies the fibre's relatively high tensile strength, which Jamshaid et al. [8] measured at 480 ± 16.2 MPa with a tenacity of 30.2 ± 1.5 cN/tex — considerably greater than sisal (380.4 MPa), coconut (176 MPa) or sugarcane bagasse (68 MPa). But the accompanying abundance of hydroxyl groups in cellulose is also what makes the fibre strongly hydrophilic.

➤ Physical and Hygric Properties

Jute fibre is fine and of high aspect ratio. Jamshaid et al. [8] report a mean diameter of 17.4 ± 1.4 μm , density 1.32 g/cm³, aspect ratio 164–345 and volume porosity 16–18%. Water absorption values reported for jute vary considerably with source and treatment: Tiwari et al. [18] give 13% for the raw chopped fibre used in their work, whereas Alene [4] reports water absorption as high as 310% for the jute used in that study, noting that this hydrophilic character can negatively affect workability and hydration.

The significance of this hygric behaviour is twofold. In the fresh state it creates competition for mixing water, reducing workability and potentially impairing hydration. In the hardened state it produces dimensional instability: the fibre swells on wetting and shrinks on drying, and because this movement is incompatible with the rigidity of the surrounding matrix it promotes microcracking of the interface, localised increases in porosity, and accelerated transfer of moisture to the fibre [3]. Onuaguluchi and Banthia [15] identify this cumulative effect of open lumen, cell wall pores and hydroxyl groups as the principal reason plant fibres are susceptible to moisture-induced dimensional instability.

Table 3 compiles the physical and chemical characteristics of jute fibre reported across the reviewed studies.

Table 3 Physical and Chemical Properties of Jute Fibre Compiled from the Reviewed Literature. Ranges Reflect Genuine Variation between Sources, Cultivars and Processing Routes.

Property	Reported value	Source
Cellulose content (%)	61–72	[2], [8]
Lignin content (%)	12–13	[2], [8]
Crystallinity (%)	60–65	[2], [8]
Fibre diameter (μm)	17.4 ± 1.4	[8]
Density (g/cm ³)	1.32	[8]
Density (g/cm ³)	1.42	[11]
Specific gravity (kg/m ³)	1460	[18]
Volume porosity (%)	16–18	[8]
Aspect ratio (length/diameter)	164–345	[8]
Tensile strength (MPa)	480 ± 16.2	[8]
Tensile strength (MPa)	400–800	[18]
Tensile strength, single filament (MPa)	278	[6]
Fibre modulus (GPa)	37.5 ± 1.4	[8]
Fibre modulus, single filament (GPa)	41	[6]

Tenacity (cN/tex)	30.2 ± 1.5	[8]
Elongation at break (%)	2.3 ± 0.1	[8]
Water absorption (%)	13	[18]
Water absorption (%)	310	[4]

➤ Implications for Durability

Taken together, these characteristics define the durability problem. A jute fibre placed in a Portland cement matrix is a porous, hydrophilic, partly alkali-soluble body embedded in a saturated, highly alkaline, dimensionally stable medium. Both chemical and physical degradation pathways are therefore available, and as Section IV sets out, they operate simultaneously and reinforce one another.

➤ Fresh and Mechanical Performance: Establishing the Dosage Regime

Durability cannot be assessed independently of dosage, because the quantity of fibre that maximises strength is not necessarily the quantity that maximises durability. This section therefore establishes the dosage regime reported in the literature, as context for what follows.

• Workability

There is complete agreement across the reviewed studies that jute fibre reduces workability, and that the reduction increases with dosage. Ahmad et al. [2] attribute this to the large specific surface area and small diameter of the fibre together with its moisture absorption, and note that at increasing volume dosage "balling" occurs, stiffening the mix. Quantitatively, Tiwari et al. [18] recorded slump values of 110, 105 and 110 mm for control M25, M30 and M40 mixes respectively, falling to 80 mm at 1.5% jute. Yogeswari and Shyam [20] observed a decline from 650 mm to 480 mm as combined steel and jute content rose. Mahi et al. [11] found that workability losses were themselves treatment-dependent, with acidic treatment producing the most severe reduction because the fibres were degraded by the treatment. The most extreme case is reported by Alene [4], where a fixed 3% jute content introduced by partial replacement of concrete constituents produced a zero-slump condition in all fibre mixes, against 65 mm for the control, accompanied by visible fibre balling and interlocking.

• Mechanical Performance and the Existence of an Optimum

The mechanical evidence consistently describes an optimum dosage beyond which performance deteriorates.

Ahmad et al. [2] place this optimum at 1–2% depending on fibre length and diameter, and state that higher doses adversely affect both strength and durability characteristics through loss of fluidity. Jamshaid et al. [7] found tensile and compressive strength increasing with cellulosic fibre content up to 2%, with further addition causing deterioration; at 2% loading, jute and sisal reinforcement produced improvements of 11.6% to 20.2% in tensile and compressive strength respectively relative to plain concrete. Notably, in the same study bending strength peaked at a lower dosage of 1.5%, with reductions beyond this attributed to cracks forming at the fibre–concrete interface.

Tiwari et al. [18] reported increases in compressive strength with jute addition across all three grades tested, with M25 rising from 26.8 MPa (control, 28 days) to 32.1 MPa at 1.5% jute, an increase of 19.7%, and split tensile strength rising from 2.6 MPa to 3.4 MPa, an increase of 30.8%. Yogeswari and Shyam [20] found an optimum of 1% steel with 0.5% jute in a hybrid system, giving 48 MPa against 45 MPa for the control at 28 days, with higher fibre contents reducing strength substantially.

A contrasting result is instructive. Alene [4] introduced jute at a fixed 3% not as an addition but as a partial replacement for cement, sand and coarse aggregate, and recorded compressive strength reductions in every case: from a control value of 33.88 MPa at 28 days to 22.64 MPa where cement was replaced (a reduction of 33.2%), 30.34 MPa for sand replacement (10.4%) and 29.26 MPa for coarse aggregate replacement (13.8%). The mechanism identified was reduced binder content and matrix disruption, compounded by increased porosity and weakened interfacial transition zones arising from poor workability and fibre balling. Importantly, all mixes nonetheless showed improved crack resistance and more gradual, ductile post-failure behaviour, and unit weight fell by 4–8%. This study usefully demonstrates that the *method* of incorporation matters as much as the quantity, and that jute functions primarily as a crack-control and energy-dissipation material rather than a strength-enhancing one.

Table 4 Mix Designs, Dosages and Principal Mechanical Outcomes of the Reviewed Jute Fibre-Reinforced Concrete Studies.

Study	Grade / matrix	Jute dosage	Fibre length	Principal outcome
Tiwari et al. [18]	M25, M30, M40	0.5, 1.0, 1.5%	25–50 mm	+19.7% compressive (M25, 28 d, 1.5%); +30.8% split tensile; slump 110 → 80 mm
Jamshaid et al. [7]	Cement matrix	0.5–3% by mass	30 mm	Optimum 2%; +11.6–20.2% tensile/compressive; bending optimum 1.5%
Jamshaid et al. [8]	OPC blocks	2% by weight	30 mm	Compressive 6.75 MPa vs 3.26 MPa control
Alene [4]	C-25, replacement	3% (replacement)	40–60 mm	–33.2% (cement), –10.4% (sand), –13.8% (coarse); unit weight –4–8%

Mahi et al. [11]	M20, w/c 0.48	0.1, 0.2, 0.4% by volume	15 mm	Alkali treatment best; split tensile 2.28 → 2.60 MPa
Yogeswari and Shyam [20]	M30 hybrid	0.5–1.5% + steel	10 mm	Optimum 1% steel + 0.5% jute: 48 MPa vs 45 MPa
Fidelis et al. [6]	Low-CH mortar	3 and 5 fabric layers	Textile	Polymer coating: +46.7% tensile stress, +91.8% strain

The practical conclusion for the present review is that jute is normally used in the range 0.1% to 2%, with most evidence supporting an optimum of 1–2% for strength and possibly lower for flexural performance. Whether this is also the durability optimum is addressed in Section VII.

➤ Durability of Jute FIBRE-Reinforced Concrete

• The Governing Mechanism: Alkaline Degradation

The dominant durability concern for all lignocellulosic fibre-cement composites is degradation of the fibre in the alkaline matrix. The mechanism has been characterised in detail, principally through work on sisal, and is now well established.

Melo Filho et al. [13] investigated sisal fibre cement composites using two matrices — one of ordinary Portland

cement (PC) and one in which 50% of the cement was replaced by metakaolin (PC–MK) — subjecting specimens to up to 25 wetting and drying cycles and to natural ageing for periods from 28 days to five years. Combining thermogravimetric analysis, Fourier transform infrared spectroscopy and scanning electron microscopy, they identified two distinct degradation mechanisms operating in the Portland cement environment. The primary mechanism is fibre mineralisation: calcium hydroxide, the principal alkaline hydration product, migrates to and precipitates within the fibre cell wall and lumen, progressively filling and stiffening the fibre structure and thereby destroying the ductility and pull-out behaviour on which composite toughness depends. The secondary and less severe mechanism is chemical: alkaline hydrolysis and decomposition of lignin and hemicellulose through adsorption of calcium and hydroxyl ions, confirmed by the disappearance of the hemicellulose peak and reduction of the lignin bands after ageing.

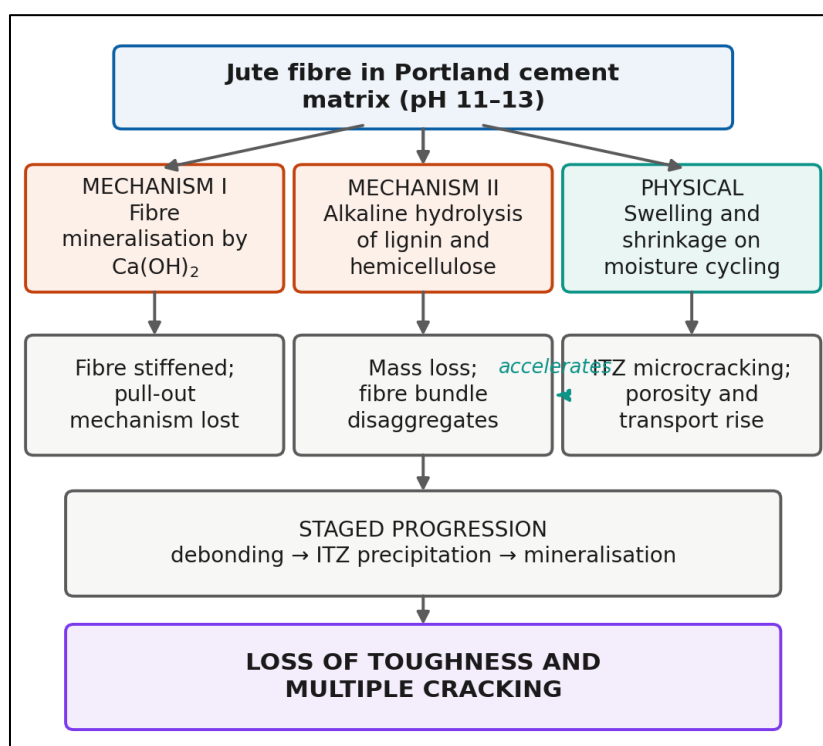


Fig 4 Degradation pathways for jute fibre in a Portland cement matrix. Two chemical mechanisms (mineralisation and alkaline hydrolysis) operate alongside a physical mechanism driven by the hygroscopicity of the fibre; the physical route accelerates the chemical ones by opening transport paths at the interface. Compiled from the mechanisms reported in [3], [12], [13] and [16].

Wei [19] resolves the process into a sequence rather than a single event. Degradation proceeds gradually from the fibre surface inward: the amorphous protective constituents, lignin and hemicellulose, deteriorate first, which permits alkaline pore solution to infiltrate the cell walls, after which the exposed cellulose microfibrils deteriorate and the fibre fails

prematurely. The same author records the three-stage account of Mohr and colleagues, in which ageing proceeds by initial debonding of the fibre from the cement, then precipitation of hydration products within the interfacial transition zone, and finally mineralisation of the fibre evidenced by increasing embrittlement. The practical significance is that the earliest

damage is interfacial and chemical rather than a loss of fibre strength, which is why composite toughness collapses well before the fibre itself is destroyed.

Alassaad et al. [3] describe the same process for bio-based fibres generally, listing alkali-induced hydrolysis of cellulose, hemicellulose and lignin; mineralisation of fibre cell walls by calcium hydroxide; swelling and shrinkage of fibres during moisture transport; weakening of the fibre–matrix interface through increased porosity, decalcification and adhesion loss; and damage from cyclic wetting–drying and freeze–thaw events. Mejia-Ballesteros et al. [12] summarise the degradation mechanism as mineralisation of the cell walls, alkali hydrolysis of lignin and hemicellulose, and cellulose decomposition including stripping of cellulose microfibrils and alkaline hydrolysis of amorphous regions in the cellulose chains.

The quantitative consequence for composite performance is severe. In the plain Portland cement system studied by Melo Filho et al. [13], toughness fell from 13.94 kJ/m² to 0.07 kJ/m² after 25 wetting and drying cycles, and bending strength reached the same value as that of the unreinforced matrix — that is, the fibre reinforcement ceased to contribute anything at all. The fracture process changed from multiple cracking to a single crack, with the number of cracks falling from 34 to one. The authors identified ten cycles as the threshold beyond which most of the degradation at the fibre and fibre–matrix interface had already occurred.

• Direct Evidence for Jute

The most directly relevant durability evidence for jute comes from the comparative accelerated ageing study of Jamshaid et al. [8], who immersed jute, sugarcane, coconut, sisal and basalt fibres in sodium hydroxide and calcium hydroxide solutions at pH 9 and 10 for one week, and additionally in 1, 2, 4 and 6 M solutions for 48 hours, before evaluating weight loss, tenacity, surface morphology, pull-out behaviour and the compressive strength of 2% fibre-reinforced concrete.

The findings for jute are unambiguous and, for the purposes of this review, central. Jute sustained the greatest weight loss of any fibre tested, approaching 25% in NaOH at pH 10, and its tenacity was the most severely affected by the ageing process of all the fibres studied. Weight loss increased with alkali concentration for all cellulosic fibres, and sodium hydroxide was consistently more aggressive than calcium hydroxide. Basalt, as a mineral fibre containing neither lignin nor hemicellulose, showed no measurable weight loss. Scanning electron micrographs showed surface degradation, diameter reduction and the development of small voids after ageing, particularly in the case of jute. The authors attribute the weight loss in cellulosic fibres directly to the dissolution of lignin and hemicellulose, consistent with the mechanism established in Section V-A.

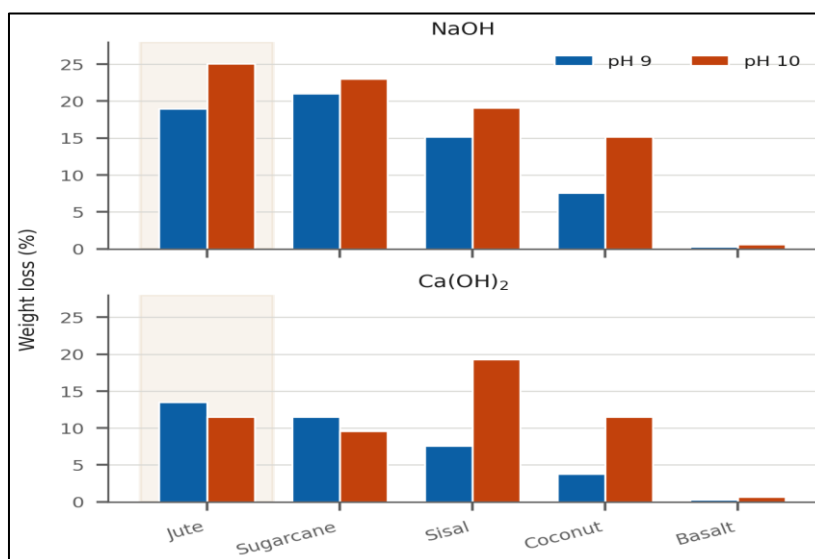


Fig 5 Weight loss of plant and mineral fibres after one week of immersion in alkaline solution at pH 9 and pH 10. Jute sustains the greatest loss of any fibre in sodium hydroxide, the more aggressive of the two alkalis; basalt, containing neither lignin nor hemicellulose, is essentially unaffected. Values digitised from the published figures of Jamshaid et al. [8] and are therefore approximate.

A second and more nuanced result from the same study deserves emphasis, because it complicates any simple ranking of jute as unsuitable. Despite degrading the most, jute performed second best of all fibres tested in both interfacial and composite terms. The apparent interfacial shear strength of jute in cement was 0.991 ± 0.05 MPa, exceeded only by basalt at 1.769 ± 0.11 MPa and higher than sisal (0.872), coconut (0.745) and sugarcane (0.663). In pull-out testing, jute

recorded a peak force of 53.54 ± 1.12 N against 82.90 N for basalt and 52.61 N for sisal; critically, jute and sisal failed by fibre pull-out, whereas sugarcane and coconut fibres ruptured, indicating their inherent weakness. In compressive testing of concrete reinforced with 2% fibre by weight, all fibres improved on the control value of 3.26 ± 0.22 MPa, with basalt highest at 10.47 MPa, followed by jute at 6.75 MPa and sisal at 5.52 MPa.

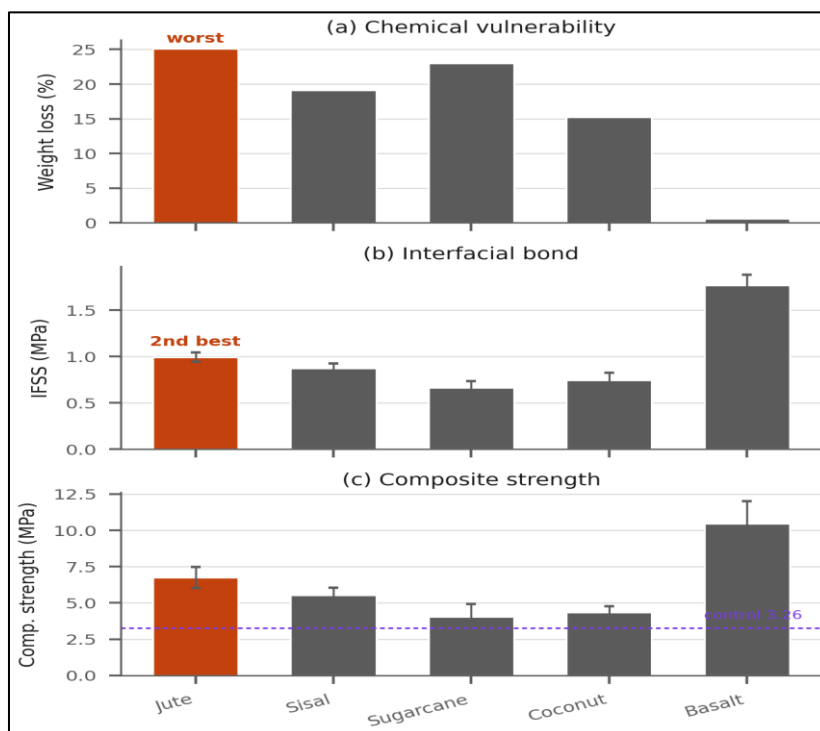


Fig 6 The vulnerability–adequacy paradox for jute. Panel (a) shows jute to be the most chemically vulnerable fibre tested, yet panels (b) and (c) show it ranking second only to basalt in interfacial shear strength and in the compressive strength of the resulting composite. Panel (a) digitised from published figures; panels (b) and (c) from Tables 4 and 6 of Jamshaid et al. [8], error bars showing the reported standard deviation of ten measurements.

The apparent contradiction resolves once initial properties are considered. Jute is chemically the most vulnerable of the plant fibres examined but begins from a substantially higher tensile strength and a favourable surface morphology that produces strong interfacial adhesion. It therefore retains useful performance despite proportionally large losses. This is a materially important observation for design: jute's suitability depends not on its resistance to alkaline attack, which is poor, but on its strength reserve and bond quality, which are good. It also implies that the case for protective treatment is strong, since the fibre has much to lose.

• Long-Term Alkaline Exposure of Jute: the Kundu Dataset

The single most complete body of jute-specific durability evidence identified in this review is that of Kundu et al. [10], and it merits separate treatment because it is the only study to follow jute fibre through a full exposure series in cementitious and simulated pore media.

Jute fibres (*Corchorus olitorius*, TD4 grade, 50 mm) were exposed in three media — cement paste at a water-to-cement mass ratio of 0.4, saturated calcium hydroxide solution

at pH approximately 14, and 0.1 N sodium hydroxide at pH approximately 13 — for 7, 14, 28, 42, 90, 180 and 360 days, with tensile strength evaluated at each interval using a two-parameter Weibull distribution over twenty-five single filaments per batch. Three fibre conditions were compared: raw, mild-alkali modified (0.5% w/v NaOH, 24 h), and combined alkali and dilute polymer modified (the alkali step followed by 10 min immersion in 0.125% v/v carboxylated styrene-butadiene rubber latex).

The unexposed fibre properties alone are instructive (Table 5). Mild alkali treatment reduced the mean fibre diameter from $66 \pm 15 \mu\text{m}$ to $56 \pm 14 \mu\text{m}$, a reduction of about 15% that the authors attribute to removal of hemicellulose, lignin and pectin and consequent compaction of the cellulose chains; equilibrium water absorption fell from $210 \pm 20\%$ to $161 \pm 14\%$; and tensile strength rose from 335 MPa to 610 MPa, an increase of 82%. Adding the polymer coating raised the diameter to $80 \pm 18 \mu\text{m}$, consistent with a surface layer rather than further removal of material, reduced water absorption further to $112 \pm 19\%$ — nearly half the raw value — and gave a tensile strength of 493 MPa, below the alkali-only figure but still 47% above raw jute.

Table 5 Properties of Raw and Modified Jute Fibre Before Exposure, from Kundu et al. [10].

Fibre condition	Mean diameter (μm)	Water absorption (%)	Tensile strength (MPa)	Elongation at break (%)
Raw	66 ± 15	210 ± 20	335	1.26
Mild alkali (0.5% NaOH, 24 h)	56 ± 14	161 ± 14	610	1.70
Combined alkali + polymer	80 ± 18	112 ± 19	493	1.74

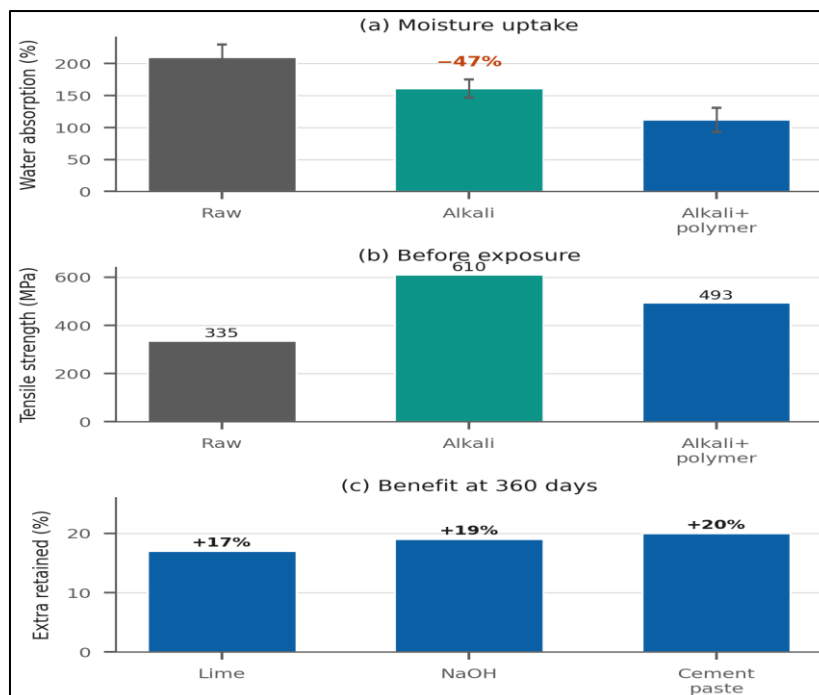


Fig 7 Effect of mild-alkali and combined alkali–polymer modification on jute fibre, from Kundu et al. [10]. Panel (a): equilibrium water absorption is almost halved by the combined treatment. Panel (b): tensile strength before exposure, showing that alkali treatment alone gives the highest virgin strength but the polymer coating trades some of this for protection. Panel (c): additional tensile strength retained relative to raw jute after 360 days in each of the three exposure media. Error bars show the reported standard deviation.

The exposure results establish two findings that bear directly on the argument of this review. First, degradation of raw jute in all three media follows a decelerating curve over 360 days rather than a linear decline, with the steepest losses occurring within the first ninety days — the same front-loaded pattern observed for sisal under wet–dry cycling (Section V-F) and consistent with the identification of an early threshold beyond which most damage has already occurred. Second, the severity of attack is strongly medium-dependent: raw jute retained substantially more of its initial strength in cement paste than in either saturated lime or sodium hydroxide solution, which indicates that simulated pore solutions overstate the degradation that occurs in a real cementitious matrix, where the fibre is partly protected by the surrounding solid phase and where free calcium hydroxide is progressively consumed.

The treatment effect is quantified directly by the authors: after 360 days of exposure, the combined alkali and polymer modified jute retained 17%, 19% and 20% more tensile strength than raw jute in saturated lime solution, sodium hydroxide solution and cement paste respectively. The mechanism was established by elemental analysis, FTIR, XRD, NMR and SEM with EDS, and attributed to the polymer coating forming a physical barrier that limits fibre mineralisation; in the authors' model, mineral attack is redirected onto the polymer chain rather than the cellulose structure beneath it.

Two implications follow. The protective effect is real but partial — a fifth of the initial strength preserved is a

meaningful gain, not a solution — so treatment mitigates rather than eliminates the durability problem. And the reduction in water absorption from 210% to 112% identifies the operative variable: since moisture is the transport vehicle for calcium hydroxide, halving the fibre's water uptake is plausibly the principal route by which the treatment works, which connects the treatment literature of Section VI-A to the transport discussion of Section V-E.

• Chemical and Acid Attack

Beyond the intrinsic alkalinity of the matrix, JFRC in service may encounter externally aggressive environments. The only study in the reviewed corpus to address this directly is that of Tiwari et al. [18], who cured JFRC specimens in a 0.5 N sulphuric acid medium for 28 days alongside normally cured controls.

Two findings emerge. First, acid curing reduced compressive strength relative to normal curing in every mix. Second, and more significantly, the magnitude of that reduction increased with jute content. For M25 concrete, the maximum strength reduction after 28 days of acid curing occurred at 1.5% jute and amounted to 37.8%; for M30, the corresponding maximum reduction, again at 1.5%, was 31.06%. The authors observed that for M30, jute addition slightly increased compressive strength under acid curing up to 1% fibre content but reduced it at 1.5%. Split tensile strength likewise decreased under acid curing, which the authors attributed to the acid medium accelerating the rate of decomposition of the jute fibre, compounded by the fibre's natural tendency to decompose over time.

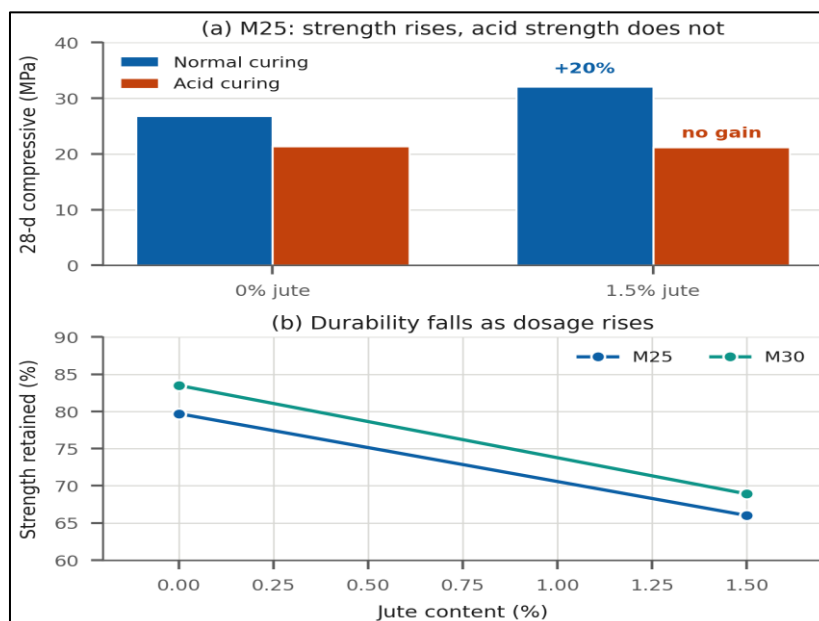


Fig 8 Divergence between strength-optimal and durability-optimal jute dosage. Panel (a): for M25 concrete, 1.5% jute raises 28-day compressive strength by 20% under normal curing but produces no corresponding gain after acid exposure. Panel (b): the proportion of strength retained after 28 days in 0.5 N sulphuric acid falls by roughly fourteen percentage points in both M25 and M30 as jute content rises from zero to 1.5%. Computed from values reported by Tiwari et al. [18]; the M30 point at 1.5% uses the strength reduction stated by those authors.

This is an important result because it demonstrates directly, for jute, the divergence between strength-optimal and durability-optimal dosage discussed in Section VI: the very dosage that maximised compressive and tensile strength under normal curing (1.5%) was the dosage that suffered the greatest deterioration under chemical attack.

- *Moisture Transport and Water Absorption*

Because moisture ingress is the vehicle for most degradation processes, the transport properties of JFRC are directly relevant to its durability. The evidence here is, at first sight, contradictory, and requires care.

Jamshaid et al. [7] report that the water absorption capacity of natural cellulosic fibre-reinforced concrete decreased substantially relative to plain concrete, but that it increased with the loading percentage of fibres. The two observations are reconcilable: at low dosage, well-dispersed fibres restrain cracking and refine the transport network, whereas at higher dosage the fibres themselves — being porous and hydrophilic — together with the entrapped air and interfacial defects associated with poor workability, provide preferential moisture pathways. This interpretation is supported by Alene [4], who attributes the density reduction of 4–8% in JFRC to the low density of jute together with increased entrapped air voids and reduced particle packing efficiency, and who identifies increased porosity and degraded interfacial transition zones as the cause of compressive strength reduction.

Alaassad et al. [3] provide the mechanistic account: water absorption and desorption lead to repeated cycles of

swelling and shrinkage that are incompatible with the rigidity of the cementitious matrix, promoting microcracking of the interface, loss of adhesion, localised increase in porosity and accelerated transfer of moisture to the fibres. Hygroscopic swelling–shrinkage thus acts both as a direct physical degradation mechanism and as an accelerator of the chemical mechanisms described above.

- *Wet–Dry Cycling and Long-Term Ageing*

Cyclic wetting and drying is the most widely used accelerated ageing protocol for lignocellulosic fibre-cement composites [3], and the results obtained with it constitute the clearest evidence of long-term vulnerability.

The severity of the effect in plain Portland cement systems has already been noted: complete loss of reinforcing function after 25 cycles, with the threshold at approximately ten cycles [13]. Claramunt et al. [5] confirm the same pattern for kraft pulp and cotton linter mortar composites subjected to four wet–dry cycles, and describe the sequence of damage reported in the literature as loss of adherence between fibre and matrix after the second cycle, reprecipitation of hydrated compounds in the void space at the former fibre–cement interface, full mineralisation, and consequent embrittlement after ten cycles. They further describe a "pump-like" effect in which the wet cycle dissolves calcium hydroxide which the fibres absorb and swell, and the dry cycle evaporates water so that calcium hydroxide precipitates on the surface and in the lumen, densifying the fibre with highly alkaline products.

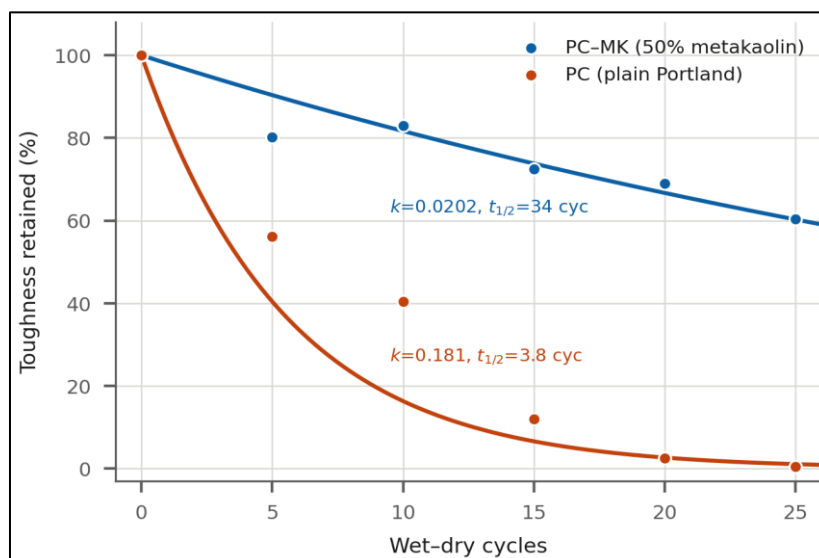


Fig 9 Loss of composite toughness with wet-dry cycling, normalised to the initial value of each system, with first-order decay models fitted for this review. The plain Portland cement composite loses half its toughness within approximately four cycles and retains under 1% after twenty-five; the metakaolin-modified composite retains 60% over the same exposure. Data from Table 3 of Melo Filho et al. [13].

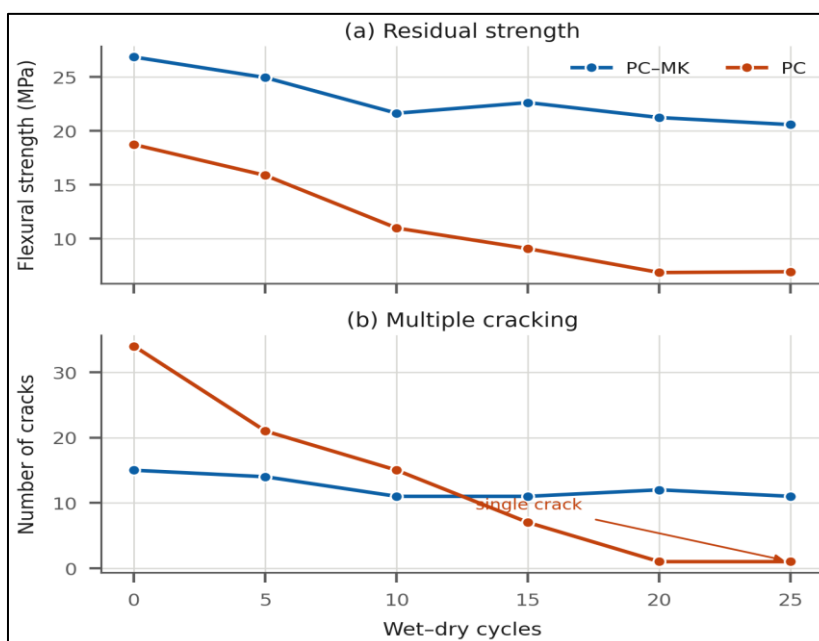


Fig 10 Residual flexural strength (a) and multiple-cracking capacity (b) against wet-dry cycles for sisal composites in plain Portland cement and metakaolin-modified matrices. The collapse from 34 cracks to a single crack in the plain matrix marks the transition from ductile multiple cracking to brittle failure. Data from Table 3 of Melo Filho et al. [13].

Long-term natural ageing produces a related but distinguishable effect. Melo Filho et al. [13] tested PC-MK composites at ages from 28 days to five years and found a progressive increase in post-cracking stiffness, with the number of cracks falling from 17 at 28 days to five at five years and toughness decreasing from 20.77 to 17.87 kJ/m², which they attributed to fibre-matrix densification with age rather than to fibre degradation, since bending strength remained essentially constant.

No study in the corpus assembled for this review subjected jute fibre-reinforced concrete itself to wet-dry cycling. Freeze-thaw exposure, by contrast, has been

examined for other plant fibres, and the results are discussed in the following section.

• Freeze-Thaw and Salt Scaling

Freeze-thaw exposure is the one aggressive environment in which the behaviour of plant fibres departs sharply from the pattern established under sustained alkaline attack, and — unusually for this review — jute-specific evidence exists.

Affan and Ali [1] tested jute fibre-reinforced concrete intended for rigid pavement at a dosage of 5% by mass of cement, equivalent to 0.8% by volume, using 50 mm fibres, and subjected specimens to 10, 20 and 30 freeze-thaw cycles

while tracking crack propagation, mass loss, dynamic modulus, damping ratio and fundamental frequency alongside compressive, split tensile and flexural strength. Mass loss in the jute composites reached up to 1.86%, which the authors attributed to the water absorption of the fibres. Despite this, they concluded that jute fibres reduce freeze–thaw effects in concrete relative to plain concrete and that the material is favourable for rigid pavement applications under such conditions.

This result is important for two reasons. It is the only identified study in which jute itself has been subjected to a cyclic aggressive environment, and it points in the opposite direction to the alkaline evidence of Section V-B: the same hydrophilicity that makes jute vulnerable to mineralisation also causes measurable mass loss under freezing, yet the net effect on composite performance is protective rather than harmful.

Two further studies on other plant fibres support and refine that conclusion. Merta et al. [14] reinforced cementitious mortars with hemp and flax at 1% by volume, with fly ash replacing cement at 25 and 50 wt%, and applied 56 freeze–thaw cycles in 3% sodium chloride solution (freezing 16–18 h at -20 ± 2 °C, thawing 6–8 h at 20 ± 2 °C). Natural fibres enhanced freeze–thaw resistance, reducing surface scaling to 5–8% after 56 cycles. The compressive strength of plain mortar decreased by up to 57% over the exposure, and the addition of natural fibres substantially reduced that loss. In flexure the contrast was sharper still: plain mortars lost 33% of their strength, against 13% for hemp, 23% for flax and 10% for polypropylene composites. Energy absorption capacity was markedly enhanced by natural fibre reinforcement, reaching up to 348% above plain mortar for hemp.

This study bears directly on jute because hemp and flax are, like jute, bast fibres extracted from the plant stem [15], and therefore the closest chemical analogues for which freeze–thaw data exist.

It also introduces a complication that qualifies the mitigation argument of Section VI-B. Under the harsh combined exposure, hemp- and flax-reinforced mortars containing 25 wt% fly ash replacement lost compressive strength significantly, although they remained competitive with synthetic fibres in flexural strength and retained energy absorption up to 48% above plain mortars. Pozzolan replacement, which is unambiguously beneficial under alkaline ageing, is therefore not uniformly beneficial under combined freeze–thaw and salt exposure. Any recommendation to lower matrix alkalinity for durability must be qualified by the exposure regime it is intended to address.

Juradin et al. [9] provide the third element, and their result carries an instructive asymmetry. Testing six mortars — a reference and five fibre-reinforced mixes at 0.5% fibre by binder mass, using sheep wool and Spanish broom with different treatments alongside polypropylene and glass — through 56 freeze–thaw cycles, they found that fibre addition reduced workability and compressive strength, and that at 56

days *no* fibre-reinforced mortar had increased flexural strength relative to the reference. After freeze–thaw exposure, however, polypropylene and NaOH-treated Spanish broom mortars exceeded the reference flexural strength by up to 23%, and all fibre-reinforced mortars showed fracture energy up to 2.6 times that of the reference, maintaining the improvement after cycling. Untreated and seawater-treated natural fibres performed poorly, and the authors concluded that these require further optimisation for durability in alkaline environments.

The asymmetry matters. The fibres conferred no benefit in virgin flexural strength but a substantial one in retained strength after damage, which is to say that their contribution is to damage tolerance rather than to strength. That distinction runs through the whole of this review: plant fibres are not primarily strengthening agents but crack-control and energy-dissipation agents, and durability assessment should be framed accordingly. It also confirms that fibre treatment governs performance under freeze–thaw as it does under alkaline attack, strengthening the argument of Section VI-A.

Three conclusions follow for jute. Plant fibres, including jute itself, improve rather than impair resistance to freeze–thaw and salt scaling, in contrast to their behaviour under sustained alkaline exposure. The benefit is conditional on fibre treatment. And the interaction between pozzolanic replacement and freeze–thaw exposure is not straightforwardly favourable, which means mitigation strategies cannot be selected on the basis of alkaline performance alone.

• *Interfacial and Microstructural Evidence*

Microstructural investigation has been decisive in establishing the mechanisms above and provides the strongest form of evidence available.

Melo Filho et al. [13] used scanning electron microscopy to compare sisal fibres extracted from PC and PC–MK composites after 25 wet–dry cycles against reference fibres. Fibres from the PC–MK matrix remained intact with no signs of degradation, whereas those from the PC matrix showed clear degradation with the cell walls mineralised, confirmed by the observation of high calcium hydroxide concentrations on the fibre surface. Silva et al. [16] performed energy-dispersive spectroscopy mapping at the fibre–matrix interface of aged composites and found a high calcium concentration inside the sisal fibre of the Portland cement composite, indicating mineralisation of the fibre-cells, against much lower calcium concentration and no signs of deterioration in the calcium-hydroxide-free composite.

For jute specifically, the scanning electron micrographs of Jamshaid et al. [8] show degradation of the fibre surface, a reduction in diameter and the development of small voids after alkaline ageing, with micro-cracks visible on both NaOH- and $\text{Ca}(\text{OH})_2$ -treated jute samples. Ahmad et al. [2] report complementary evidence on the effect of treatment, with untreated jute showing fibre pull-out and visible gaps at the interface, and hot-alkali-treated fibres showing almost undetectable pull-out and gaps.

• Quantitative Synthesis of Degradation Kinetics

The studies reviewed above report degradation in incommensurable units and under incompatible exposure regimes, which prevents formal meta-analysis (Section VII-F). Where a single study reports a complete exposure series, however, the rate of degradation can be characterised quantitatively, and doing so makes the effect of matrix modification explicit.

The toughness data of Melo Filho et al. [13], which span six exposure levels from zero to twenty-five wet–dry cycles for two matrices, were normalised to their respective initial values and fitted with a first-order decay model of the form

$$R(n) = \exp(-kn)$$

Where R is the fraction of initial toughness retained, n is the number of wet–dry cycles and k is a rate constant. The model was constrained to pass through the measured initial value and fitted by least squares on $\ln R$. It is emphasised that this is a descriptive characterisation of the rate of property loss, not a mechanistic kinetic model: the underlying degradation involves at least three concurrent processes (Section V-A) and no claim is made that any of them is individually first-order. The fits are shown in Figure 9 and summarised in Table 6.

Table 6 Descriptive First-Order Decay Parameters for Composite Toughness Under Wet–Dry Cycling, Fitted for this Review to the Data of Melo Filho et al. [13].

Matrix	Rate constant k (cycle ⁻¹)	Half-life $t_{1/2}$ (cycles)	R^2	Toughness retained at 25 cycles
Plain Portland cement (PC)	0.181	3.8	0.89	0.5%
50% metakaolin (PC–MK)	0.0202	34.2	0.88	60.3%
Ratio (PC : PC–MK)	9.0	0.11	—	0.008

Kinetic treatment of this problem is not without precedent. Wei [19] investigated the degradation behaviour and kinetics of sisal fibre in the pore solutions of cementitious composites containing metakaolin and developed a service-life prediction model for cellulose in cement, reporting that incorporating 30 wt% metakaolin reduced the hydroxide ion concentration, rendered the pore solution unsaturated with respect to calcium hydroxide after seven days, and extended the service life of the cellulose by a factor of 13.7.

Two observations follow from Table 6. First, the decay constant for the plain Portland cement system is nine times that of the metakaolin-modified system, so the benefit of pozzolanic substitution can be stated as an order-of-magnitude reduction in the rate of toughness loss rather than merely as an improvement in endpoint values. That this figure of nine, derived here from composite toughness under wet–dry cycling, sits close to the factor of 13.7 that Wei [19] obtained for cellulose service life from pore-solution chemistry is a useful independent corroboration: two different response variables, two different exposure methods and two different laboratories converge on an order-of-magnitude benefit from metakaolin substitution. Second, the half-life of composite toughness in a plain Portland cement matrix is under four wet–dry cycles, which is consistent with the independent observation by Claramunt et al. [5] that loss of fibre–matrix adherence begins after the second cycle and with the identification by Melo Filho et al. [13] of ten cycles as the threshold beyond which most degradation has already occurred.

The same treatment cannot yet be applied to jute, but the reason is more specific than a simple absence of data. Kundu et al. [10] report a seven-point exposure series for jute in three media over 360 days (Section V-C), which is in principle sufficient for kinetic analysis. What that dataset characterises, however, is the residual tensile strength of the *fibre*, whereas the analysis above concerns the toughness of the *composite*.

The two are not interchangeable: composite toughness depends on fibre–matrix bond and on the pull-out mechanism as well as on fibre strength, and it is the collapse of the pull-out mechanism through mineralisation, rather than fibre strength loss alone, that destroys post-cracking ductility (Section V-A). A jute composite tested through a defined exposure series, with toughness as the response variable, remains the missing measurement, and is identified accordingly as a research priority in Section VII.

IV. MITIGATION STRATEGIES

Two broad strategies exist for improving the durability of lignocellulosic fibre–cement composites: modifying the fibre so that it better resists the matrix, and modifying the matrix so that it is less aggressive to the fibre [5]. Both are represented in the reviewed literature, and the most recent evidence indicates that they are most effective in combination.

➤ Fibre Surface Treatment

• Alkali Treatment

Treatment with sodium hydroxide is the most widely applied and best-evidenced surface treatment for jute. Its mechanism is the controlled removal of hemicellulose, lignin, pectin and waxes from the fibre surface, which roughens the surface, increases the effective surface area, raises the cellulose fraction and crystallinity, and improves stress transfer from matrix to fibre [2]. Ahmad et al. [2] report a study in which hot alkali treatment at 120 °C for 90 minutes at 6% NaOH increased the tensile strength, flexural strength, tensile modulus and flexural modulus of jute fabric-reinforced composites by 37.5%, 72.3%, 23.2% and 72.2% respectively relative to untreated fabric.

Mahi et al. [11], working in Bangladesh with M20 concrete and jute at 0.1%, 0.2% and 0.4% by volume, compared alkali treatment (6% NaOH), acidic treatment (2%

HCl) and hot water treatment (80–100 °C). Alkali treatment produced the best outcomes for both workability and strength, with split tensile strength rising from 2.28 MPa for the control to 2.60 MPa for alkali-treated fibre at 0.1%, against 2.55 MPa for hot water and 2.45 MPa for acidic treatment at the same dosage. The authors attributed the improvement to removal of

lignins and hemicellulose enhancing the fibre–matrix bond, and concluded that alkali treatment is the most effective approach for improving the strength and workability of JFRC. Acidic treatment performed worst, degrading the fibres and producing the largest reduction in workability.

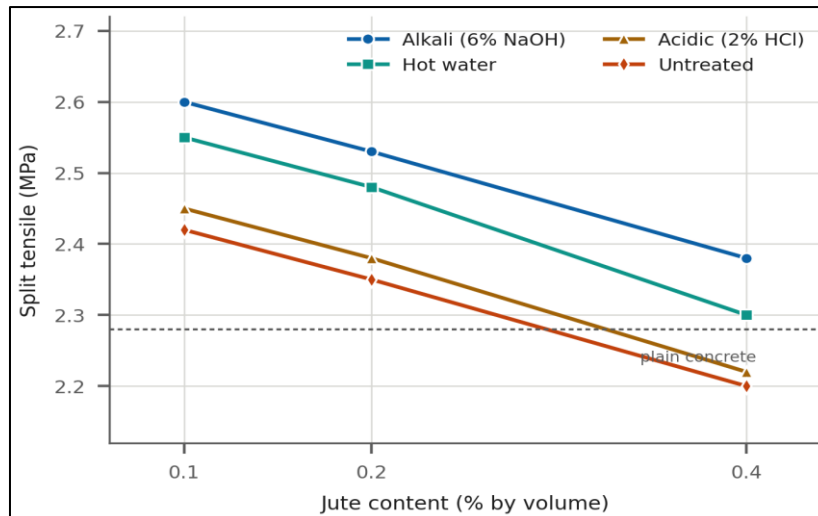


Fig 11 Effect of surface treatment and dosage on the 28-day split tensile strength of jute fibre-reinforced concrete. Alkali treatment is the most effective at every dosage and acidic treatment the least; all treatments decline as fibre content rises, reproducing the dosage effect discussed in Section IV-B. Data from Mahi et al. [11].

An important caveat applies. Ahmad et al. [2] note that while alkali treatment enhances compatibility, it also diminishes fibre strength, and that excessive alkali concentration damages the fibre and causes a considerable reduction in strength; optimal concentration must therefore be established rather than assumed.

- **Polymer Coating**

Impregnation with a polymer provides a physical barrier between fibre and matrix while improving anchoring. Fidelis et al. [6] produced jute textile-reinforced concrete using a styrene-butadiene polymer coating and a matrix with low calcium hydroxide content, and found that composites reinforced with five layers of fabric impregnated for 50 minutes developed tensile stress 46.7% higher and strain 91.8% higher than equivalent untreated composites. The treated specimens also displayed a greater number of cracks at smaller spacing, indicating improved fibre–matrix stress transfer, and the authors observed that the treatment waterproofs the fibre.

- **Hornification**

Hornification is a physical treatment consisting of repeated drying and rewetting cycles which produce an irreversible reduction in the water retention value of the fibre through rearrangement and formation of hydrogen bonds in the cellulose. Claramunt et al. [5] applied four wet–dry cycles to softwood kraft pulp and cotton linters, reducing the water retention value of kraft pulp from 126% to 90%, and reported that composites made with hornified fibres showed superior mechanical performance and durability. After ageing, hornified-fibre composites showed flexural strength approximately 13% (kraft) and 21% (cotton linter) higher and

compressive strength approximately 20% and 10% higher than composites with untreated fibres; the loss of fracture energy on ageing was reduced from 47% to 24% for kraft pulp. The benefit arises from two effects: greater dimensional stability, which reduces damage at the interface during moisture cycling, and lower water retention, which reduces the formation of calcium hydroxide incrustations on and within the fibre, thereby limiting mineralisation.

No study in the reviewed corpus applied hornification to jute fibre.

➤ **Matrix Modification: Reducing Alkalinity**

The alternative strategy attacks the cause rather than protecting the fibre: if calcium hydroxide drives mineralisation, then consuming it should arrest the process. This is achieved by partial replacement of Portland cement with pozzolanic materials, which react with calcium hydroxide to form additional calcium silicate hydrate.

The evidence for this approach is the strongest in the entire durability literature on plant fibre composites. Melo Filho et al. [13] showed by thermogravimetric analysis that replacing 50% of Portland cement with metakaolin produced a matrix in which no calcium hydroxide was detectable at 28 days, against 0.1 g/g of the calcined mass for the plain Portland cement matrix. The mechanical consequence was decisive: after 25 wet–dry cycles the PC–MK composite retained a toughness of 10.31 kJ/m² and a bending strength of 20.58 MPa and continued to exhibit multiple cracking, whereas the plain PC composite had fallen to 0.07 kJ/m² and to the strength of the unreinforced matrix.

Silva et al. [16] reached the same conclusion using a different ageing protocol and a different pozzolanic system. Their calcium-hydroxide-free matrix, produced by replacing 50% of cement with metakaolin and 20% with calcined waste crushed clay brick, was subjected to hot water immersion at 60 °C for six months. The CH-free composite suffered no mechanical degradation whatever: modulus of rupture was 23.25 MPa after ageing against 23.21 MPa before, and

toughness 28.00 kJ/m² against 29.66 kJ/m², with multiple cracking preserved. The Portland cement composite over the same exposure fell from 21.08 MPa to 6.06 MPa in modulus of rupture and from 18.12 kJ/m² to 0.66 kJ/m² in toughness. In direct comparison, the aged CH-free composite exhibited an ultimate bending strength 3.8 times higher and a toughness 42.4 times higher than the aged Portland cement composite.

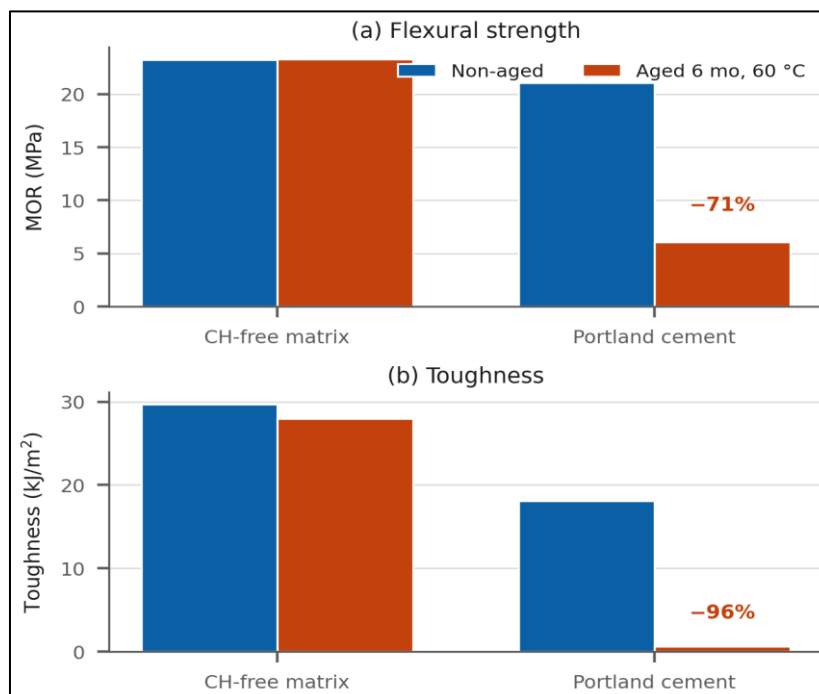


Fig 12 Effect of eliminating calcium hydroxide from the matrix on the retention of mechanical properties after six months of hot-water immersion at 60 °C. The calcium-hydroxide-free composite is statistically unchanged by the exposure, while the Portland cement composite loses 71% of its flexural strength and 96% of its toughness. Data from Table 5 of Silva et al. [16].

Mejia-Ballesteros et al. [12] extended the approach to an industrial by-product, using activated coal mining waste at 27% replacement of cement, and confirmed that the lower calcium hydroxide content of composites containing the pozzolan (11.7% against 16.1% for an inert limestone filler) indicates a lower alkalinity of the matrix and can therefore be used to decrease fibre mineralisation.

Of particular relevance to jute, Fidelis et al. [6] employed a low-calcium-hydroxide matrix with 40% metakaolin and 10% fly ash specifically to protect jute fabric reinforcement, selecting the composition on the basis of thermogravimetric analysis to obtain a matrix with reduced calcium hydroxide content at 28 days. This remains one of very few applications of the principle to jute.

➤ Combined Treatment and the Current State of the Art

The most recent work indicates that the two strategies are complementary rather than alternative. Mejia-Ballesteros et al.

[12] evaluated hornification of eucalyptus pulp and partial cement substitution by activated coal mining waste, separately and together, under 200 accelerated ageing cycles. They found that after accelerated ageing both fibre treatment and matrix modification contribute to mitigating the degradation of the fibres and increase the mechanical properties of the composites, and that aged composites combining the pozzolan with hornified fibres presented a specific energy 1.8 times higher than aged composites containing the pozzolan with untreated fibres. Their conclusion was that the combined use of hornification and partial replacement of cement by the pozzolanic residue is an efficient option for improving durability. Alasaad et al. [3] likewise describe approaches combining matrix design and fibre modification as increasingly the focus of study.

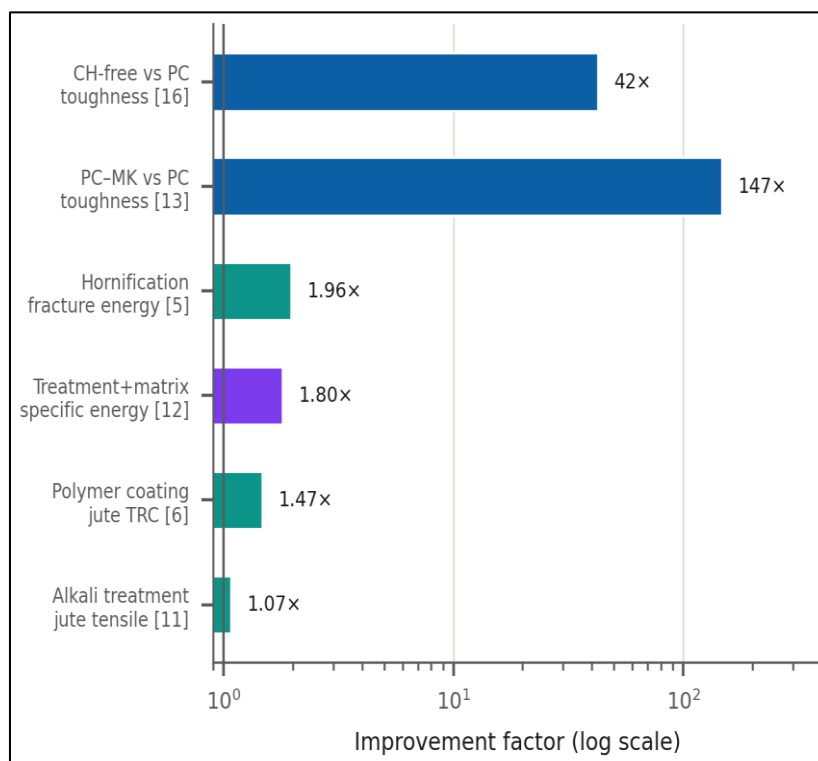


Fig 13 Reported effectiveness of mitigation measures, each expressed as the improvement factor relative to its own untreated or unmodified comparator within the same study. Matrix modification (blue) produces improvements of one to two orders of magnitude in retained properties after ageing, whereas fibre treatment alone (teal) produces improvements of tens of percent. The measures are not commensurable — they derive from different exposure protocols, different fibres and different response variables, as set out in Table 7 — and the figure should be read as a qualitative ordering of effect size, not as a pooled estimate.

The 147-fold value for PC–MK reflects a comparator toughness of 0.07 kJ/m², that is, essentially complete loss.

➤ Dosage Control and Hybridisation

Two further mitigation levers emerge implicitly from the evidence. The first is dosage control, discussed in Section VII. The second is hybridisation with a more durable fibre. Yogeswari and Shyam [20] combined jute with steel fibre and obtained their best performance at 1% steel with 0.5% jute, and Alene [4] recommends investigation of hybrid fibre systems combining jute with synthetic or mineral fibres to optimise both strength and ductility. The comparative data of Jamshaid et al. [8], in which basalt fibre proved essentially immune to alkaline attack while jute degraded most, suggest that jute–basalt hybridisation may be a productive direction, though no such study was located.

V. CRITICAL DISCUSSIONS AND RESEARCH GAPS

➤ The Durability Optimum May be Lower than the Strength Optimum

The single most consequential synthesis to emerge from this review concerns dosage. The mechanical literature

converges on an optimum jute content of 1–2% [2], with strength rising to that level and falling beyond it. But three independent lines of evidence indicate that durability performance peaks at a lower dosage.

First, Tiwari et al. [18] found that the strength reduction caused by sulphuric acid exposure grew with jute content, reaching 37.8% at 1.5% jute in M25 concrete — the same dosage that gave the best strength under normal curing. Second, Jamshaid et al. [7] found that although water absorption of natural fibre-reinforced concrete decreased overall relative to plain concrete, it increased with fibre loading percentage, indicating that transport resistance deteriorates as dosage rises. Third, the same study found the optimum dosage for bending strength (1.5%) to be lower than that for tensile and compressive strength (2%), with the reduction beyond 1.5% attributed to cracking at the fibre–concrete interface — a defect that is also a durability liability.

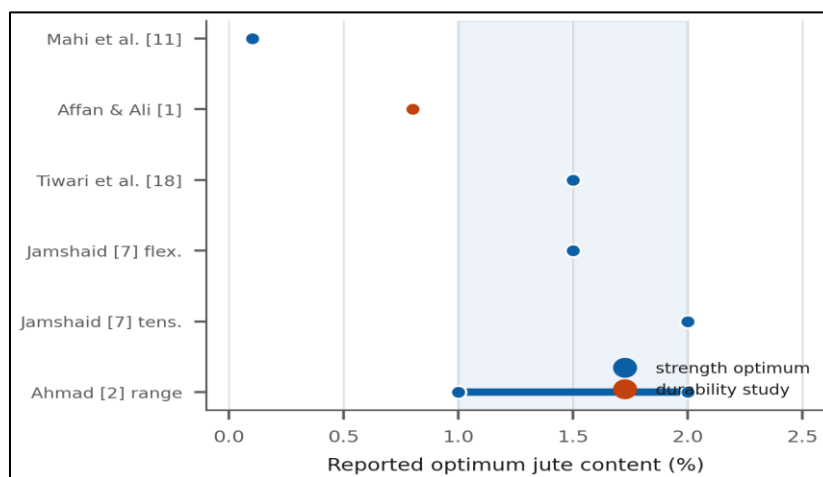


Fig 14 Optimum jute contents reported across the reviewed studies, distinguished by whether the optimum was established against a strength criterion or simply adopted as the dosage in a durability study. The strength optima converge on the 1–2% band, but no study has reported a dosage optimised against a durability criterion.

The implication is that optimum dosage recommendations derived solely from 28-day strength testing may be unsafe for structures exposed to aggressive environments, and that dosage optimisation should be performed against durability criteria explicitly. No study in the reviewed corpus has done this.

➤ Chemical Vulnerability and Mechanical Adequacy are Distinct Questions

The results of Jamshaid et al. [8] establish that jute is simultaneously the most chemically vulnerable of the common plant fibres and among the best performing in composite terms. Any assessment of jute that considers only mass loss or only composite strength will therefore reach a misleading conclusion. The correct inference is that jute possesses a strength reserve and bond quality sufficient to tolerate substantial degradation, which makes it a credible reinforcement, and simultaneously that it is the plant fibre with most to gain from protective treatment or matrix modification. The literature has not yet framed the question in these terms.

➤ Mechanistic Knowledge for Jute Exists at Fibre Level But Not in the Composite

The scale of the imbalance can now be stated quantitatively. Song et al. [17] screened 937 records and analysed 143 experimental studies of the mechanical strength of jute-reinforced cementitious composites. Against that, the present review identified two studies that subjected jute-reinforced concrete to a defined aggressive exposure — acid curing [18] and freeze–thaw cycling [1] — together with one comparative alkaline-immersion study of jute fibre itself [8]. The mechanical literature therefore exceeds the durability literature by roughly two orders of magnitude.

The degradation mechanisms set out in Section V-A — calcium hydroxide mineralisation and alkaline hydrolysis of lignin and hemicellulose — are firmly established, but almost entirely on other fibres. The definitive mechanistic studies were performed on sisal [13, 16], eucalyptus pulp [12], and softwood kraft pulp and cotton linters [5]. Jute-specific

evidence is limited to the alkaline immersion and microscopy of Jamshaid et al. [8] and the acid curing of Tiwari et al. [18].

The transfer is chemically reasonable, since jute shares the cellulose–hemicellulose–lignin structure of these fibres, and it is partly corroborated: Kundu et al. [10] applied FTIR, XRD, NMR and SEM–EDS to jute exposed in cement paste and alkaline solutions and confirmed that mineralisation is the operative process, with a polymer coating acting by impeding it. Mechanistic knowledge of jute is therefore not absent, as the earlier literature implied, but it is confined to the fibre in isolation.

The differences between jute and its analogues nonetheless remain material. Its lignin content of 12–13% is markedly lower than coconut's 42–46% and closer to sisal's 8–11%, while its crystallinity of 60–65% is lower than sisal's 68–70% [8]; and, as Section III-A notes, reported lignin contents for jute themselves span 6.6% to 45% across sources [17]. These differences would be expected to affect both the rate and the pathway of degradation. The remaining gap is therefore narrower and more precise than a general absence of mechanism: what is missing is characterisation of jute fibres *extracted from aged composites*, of the kind Melo Filho et al. [13] performed for sisal, which is the only way to observe the interaction between fibre degradation and interfacial behaviour in situ.

➤ Fibre Treatment is Validated for Jute; Matrix Modification is Not

The mitigation literature divides more sharply than the mechanistic one. Fibre treatment has now been validated for jute directly and over a long duration: Kundu et al. [10] demonstrated that combined mild-alkali and polymer modification preserves 17–20% more tensile strength than raw jute after 360 days in cement paste and simulated pore solutions. This is the strongest jute-specific durability result available, and it should be regarded as established rather than transferred.

Matrix modification is a different matter. The low-alkalinity approach, which is the most effective intervention known for any plant fibre, has been demonstrated with metakaolin for sisal [13, 16], with activated coal mining waste for eucalyptus [12] and with calcined clay brick for sisal [16]. Its only application to jute in the corpus assembled here is by Fidelis et al. [6], who used a 40% metakaolin and 10% fly ash matrix for jute textile reinforcement, but that study evaluated short-term tensile behaviour and the effect of polymer coating rather than retention of properties under ageing. No study was identified that subjected jute fibre-reinforced concrete in a low-alkalinity matrix to accelerated ageing and reported the resulting property retention. Hornification has likewise been validated for wood pulp and cotton linters [5] and eucalyptus [12] but not applied to jute.

The asymmetry is worth stating plainly, because it determines where effort should go. The fibre side of the mitigation problem is solved for jute at least in principle; the matrix side is not, and the matrix side is the one that produced complete elimination of degradation in the sisal literature [16]. Combining a treated jute fibre with a low-alkalinity matrix — the combination that Mejia-Ballesteros et al. [12] found most effective for eucalyptus — has not been attempted for jute.

Given that Bangladesh and India possess both large jute production and substantial supplies of suitable pozzolanic materials, this is a practically as well as scientifically significant omission.

➤ *Exposure Conditions Examined and Unexamined for Jute*

The exposure record for jute is uneven rather than empty, and stating it precisely matters because the gaps that remain are narrower than a general absence of durability data.

Three aggressive exposures have been applied to jute. Sulphuric acid curing was examined by Tiwari et al. [18], who found strength loss increasing with fibre content. Long-term alkaline exposure in cement paste, saturated lime and sodium hydroxide over 360 days was examined by Kundu et al. [10], at fibre rather than composite level. Freeze–thaw cycling was examined by Affan and Ali [1], who reported mass loss up to 1.86% but a net reduction in freeze–thaw damage relative to plain concrete. Comparative alkaline immersion of jute fibre against other plant and mineral fibres was reported by Jamshaid et al. [8].

Four exposures remain unexamined for jute in the literature identified here. No study subjected jute fibre-reinforced concrete to wet–dry cycling, which is the standard accelerated-ageing protocol for this class of material [3] and the condition under which plain Portland cement composites with sisal lose their reinforcing function entirely [13]; this is the most conspicuous omission, because it is the protocol on which the mechanistic literature for other fibres rests. Carbonation, chloride ingress and sulphate attack were likewise not addressed for jute, and chloride and sulphate resistance are directly relevant to the coastal and saline-groundwater conditions prevailing in the principal jute-producing regions.

A fifth gap concerns response variables rather than exposures. Where jute has been aged, the reported response has been fibre tensile strength [10], mass loss [1, 8] or residual compressive and tensile strength [18]. Toughness and multiple-cracking capacity, which are the properties that collapse first in other fibre systems [13, 16] and the properties for which fibres are added in the first place, have not been reported for aged jute composites at all.

➤ *Methodological Gaps*

Finally, the reviewed literature exhibits the methodological weaknesses identified generally by Alassaad et al. [3]: the absence of standardised accelerated ageing and alkali-challenge protocols for biofibre–cement systems, limited long-term field performance data, and the absence of predictive degradation models incorporating biological factors.

Table 7 makes the problem explicit. The durability studies surveyed here share no common exposure variable, no common response variable and no common dosage convention. Exposure ranges from one week of immersion at pH 9–10 to six months of hot-water immersion at 60 °C and from twenty-five to two hundred wet–dry cycles; response is variously reported as mass loss, tenacity, residual compressive strength, modulus of rupture, toughness or specific energy; and dosage is expressed by volume [11], by mass [7], by weight of fibre in the mix [8] and by replacement of constituents [4].

Table 7 Exposure Protocols, Response Variables and Dosage Conventions in the Reviewed Durability Studies, Showing the Heterogeneity that Currently Prevents Quantitative Pooling.

Study	Fibre	Exposure protocol	Response variable(s)	Dosage basis
Jamshaid et al. [8]	Jute, sisal, sugarcane, coconut, basalt	NaOH and Ca(OH) ₂ at pH 9 and 10, 1 week; 1–6 M, 48 h	Weight loss, tenacity, IFSS, pull-out force, compressive strength	% by weight (2%)
Tiwari et al. [18]	Jute	0.5 N H ₂ SO ₄ , 28 days	Compressive and split tensile strength	% (0.5–1.5)
Melo Filho et al. [13]	Sisal	25 wet–dry cycles; natural ageing 28 d – 5 yr	Flexural strength, toughness, crack count	% by volume (5%)
Silva et al. [16]	Sisal	Hot-water immersion, 60 °C, 6 months	Modulus of rupture, toughness, sorptivity	% by volume (10%)

Claramunt et al. [5]	Kraft pulp, cotton linters	4 wet–dry cycles	Flexural and compressive strength, fracture energy	% by weight (4%)
Mejia-Ballesteros et al. [12]	Eucalyptus pulp	200 wet–dry cycles	MOR, specific energy, limit of proportionality	% by mass
Jamshaid et al. [7]	Jute, sisal, sugarcane, coconut	None (water absorption only)	Water absorption, mechanical properties	% by mass (0.5–3)

The consequence for the present review is methodological and worth stating plainly. A formal meta-analysis, or a data-driven or machine-learning model of jute fibre durability, cannot legitimately be constructed from this corpus: with fewer than a dozen durability studies, no shared exposure metric and no shared response metric, any pooled effect size or fitted model would be an artefact of the heterogeneity rather than a property of the material. The descriptive kinetic analysis presented in Section V-H is therefore confined to a single study that reports a complete exposure series, and is offered as a characterisation of that dataset rather than as a synthesis across studies. Establishing a standardised accelerated-ageing protocol — and, with it, a body of comparably reported data on jute — is the precondition for the quantitative synthesis and predictive modelling that this field currently cannot support, and is itself a worthwhile research objective.

VI. CONCLUSIONS

This review consolidated the available evidence on the durability of jute fibre-reinforced concrete. The following conclusions are drawn.

- The durability of JFRC is governed by the alkaline pore environment of the Portland cement matrix, acting through two coupled chemical mechanisms — mineralisation of the fibre cell wall by calcium hydroxide precipitation, and alkaline hydrolysis of lignin and hemicellulose — compounded by physical degradation arising from hygroscopic swelling and shrinkage. Degradation is staged rather than uniform: debonding and interfacial precipitation precede fibre mineralisation, which is why composite toughness collapses well before the fibre itself is destroyed.
- Jute is the most chemically vulnerable of the commonly used plant fibres, sustaining the greatest mass loss and the most severe loss of tenacity under comparative alkaline ageing. It nonetheless ranks second only to basalt in interfacial shear strength, pull-out resistance and composite compressive strength, because it begins from a substantially higher initial strength and develops strong adhesion. Chemical vulnerability and mechanical adequacy are distinct questions, and jute is the plant fibre with most to gain from protective treatment.
- The optimum jute dosage for durability appears to be lower than the 1–2% optimum established for strength. Acid-induced strength loss increases with jute content, water absorption rises with fibre loading, and flexural performance peaks at a lower dosage than compressive and tensile performance. Dosage optimisation based on 28-day

strength alone is therefore unsafe for aggressive exposure conditions.

- Fibre treatment is effective and, for jute, now directly established over a long duration. Combined mild-alkali and dilute-polymer modification preserves 17–20% more tensile strength than raw jute after 360 days in cement paste, saturated lime and sodium hydroxide solutions, and halves the fibre's equilibrium water absorption. The protection is partial rather than complete, so treatment mitigates the durability problem without solving it.
- Matrix modification through pozzolanic substitution is the more powerful intervention and can eliminate mechanical degradation entirely under accelerated ageing, but it has not been applied to jute. Replacing half the Portland cement with metakaolin reduces the first-order rate constant for toughness loss from 0.181 to 0.0202 per wet–dry cycle, a ninefold reduction consistent with an independently reported 13.7-fold extension of cellulose service life. The combination that proved most effective for other fibres — a treated fibre in a low-alkalinity matrix — remains untested for jute and is the most promising single experiment this review can identify.
- Freeze–thaw is the exception to the degradation narrative. Jute fibre-reinforced concrete sustains measurable mass loss under freezing, yet reduces freeze–thaw damage relative to plain concrete, and bast fibres closely related to jute substantially reduce flexural strength loss and surface scaling. The benefit is conditional on fibre treatment, and pozzolanic replacement — unambiguously helpful under alkaline ageing — is not uniformly helpful under combined freeze–thaw and salt exposure. Mitigation strategies cannot therefore be selected on alkaline performance alone.
- The principal research priorities follow directly. A jute composite should be tested through a defined exposure series with toughness, not fibre strength, as the response variable; treated jute should be combined with a low-alkalinity matrix and aged; jute fibres should be characterised after extraction from aged composites rather than in isolation; dosage should be optimised against durability criteria explicitly; and standardised ageing protocols and dosage conventions should be adopted. The last is a precondition for the rest, since until exposure and response are reported on common scales the quantitative synthesis that would place JFRC on a design footing cannot be undertaken.

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➤ Conflicts of Interest:

The authors declare no conflict of interest.

➤ Data Availability:

No new experimental data were generated. All data analysed in this review are taken from the cited publications; the extraction matrix underlying Table 2 is available from the corresponding author on request.

➤ Use of AI Tools:

Generative AI assistance was used for literature screening support, data extraction into a common matrix, figure preparation and language editing. All source publications were read by the authors, all extracted values were verified against the original articles, and the authors take full responsibility for the content, interpretation and conclusions of this work.

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